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MANUFACTURE OF A PROTOTYPE HIGH ENERGY BEAM
VACUUM TUBE

M. Islam, Z. Jennings, W. Wells

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MANUFACTURE OF A PROTOTYPE HIGH ENERGY BEAM
VACUUM TUBE

FABRICATION D'UN PROTOTYPE DE TUBE À VIDE À FAISCEAU
DE GRANDE ÉNERGIE

M. Islam, Z. Jennings, W. Wells

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TR-MTC-001
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G. McGregor,
General Manager/Gérant général
Manufacturing Technology Centre/
Centre de technologie, fabrication

E. H. Dudgeon
Director/Directeur
Division of Mechanical Engineering
Divison de génie mécanique

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ABSTRACT

This report describes features of the fabrication development of a prototype carbon fibre composite and aluminium high-energy vacuum beam tube as an alternative to conventional beryllium tubes for accelerator applications. The development was a joint undertaking between NRCC and the Physics departments of the Universities of York and Toronto.

The prototype tube was developed for use in Canadian experiments being conducted in the DESY high-energy electron positron collision facility in Hamburg, West Germany.

RÉSUMÉ

Le présent rapport décrit les caractéristiques de la mise au point du procédé de fabrication d'un prototype de tube à vide à faisceau de grande énergie, fait d'un mélange carbone-fibre et d'aluminium, destiné à remplacer les tubes en béryllium classiques dans les accélérateurs. Cette activité de mise au point a été réalisée conjointement par le CNRC et les départements de physique des universités York et de Toronto.

Le prototype de tube a été mis au point pour servir dans des expériences canadiennes effectuées au centre DESY d'étude des collisions entre positons et électrons de grande énergie, à Hambourg (Allemagne de l'Ouest).

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MANUFACTURE OF A PROTOTYPE HIGH ENERGY BEAM VACUUM TUBE

1.0 INTRODUCTION

The Manufacturing Technology Centre (MTC), at NRCC's Montreal Road Campus was approached by Professor Frisken of York University to help simplify the manufacture of beam tubes for the ARGUS detector to be used in the DESY accelerator located in Hamburg, West Germany.

The beam tube is part of the accelerator system where collisions take place between high-energy electron and positron beams. Not only must the tube be a high-integrity vacuum vessel, it must also be a 'window' for the particles produced in the collision. If for example, the vacuum deteriorates beyond 10^{-9} torr, unwanted collisions between residual beam particles and gas atoms become a source of background noise. Particles such as mesons, photons and leptons must pass through the vessel wall in order to be detected by the ARGUS measuring system. The tube wall material therefore, has to have a low mass and atomic number to minimize altering the trajectories of the particles.

Beryllium, has all the desired properties for this purpose and has been used for such beam tubes. However, its toxic character poses potential health hazards both in manufacture and application. Should a beam tube fail in the presence of such high energy, there is a risk of evaporating the beryllium and contaminating the entire system.

The risks associated with beryllium prompted the investigation of alternative materials.

2.0 DESIGN CONSIDERATIONS

Carbon fibre epoxy composite, with a density of 1.6 gm/cm³, atomic number of 6 and high tensile modulus, developed primarily for the aerospace industry, appeared promising for this application. The material is considerably less expensive than beryllium and eliminates all inherent toxicity problems. Carbon fibre epoxy composites however, are not suitable for high vacuum use as such, because of inherent outgassing problems. Further, the material is not a good electrical conductor (this is important since any interruptions in the electrical characteristics of the chamber reduces the life of the stored beam). Thus, in order to use carbon fibre epoxy composites for beam tubes, the inside of the tubes would have to be lined with a suitable material capable of holding high vacuum and providing a continuous electrical path. High energy physicists at York University and the University of Toronto were already developing the carbon fibre epoxy composite technology, and the MTC had already developed the capability to make the very thin inside metal liners. A collaboration was set up under which the MTC produced the thin liner tubes and the University scientists finished the fabrication by baking on the carbon composite tubes.

Commercially pure aluminium rolled sheet was selected as the liner material. Radiation length calculations showed that a liner wall thickness of 0.127 mm (max.) reinforced by 1 mm thick carbon fibre epoxy composite would provide adequate radiation and electrical characteristics, along with sufficient structural strength and stiffness.

Figure 1 shows the general dimensions of the tube assembly. The central 500 mm of the assembly consists of a thin-walled aluminium liner (0.127 mm thickness) reinforced by 1 mm thick carbon fibre epoxy composite. A thicker end tube (2 mm thickness) is joined to each end of the central thin tube such that the inner diameter of the entire assembly is 80 mm. The success of this type of vacuum tube design depends on the following two conditions:

- (i) All the joints on the liner are of very high integrity and the carbon fibre epoxy is not exposed to the vacuum system at any point.
- (ii) The inside liner does not separate or buckle away from the carbon fibre epoxy reinforcement.

3.0 MANUFACTURING PROCEDURES

The tube assembly was fabricated in the following steps:

1. Fabrication of thin-walled aluminium tube with 0.127 mm wall thickness, 80 mm inside diameter and 500 mm length.
2. Welding of 2 mm thick, 80 mm inside diameter and 150 mm long end tubes to the thin tube.
3. Lay-up and curing of carbon fibre epoxy reinforcement to the thin central section.

In the following sections, steps 1 and 2 are described in detail. Step 3 was performed by the Physics Departments of York University and the University of Toronto because suitable curing facilities were not available in the MTC at that time.

3.1 Fabrication of the Thin-walled Central Tube

Since 80 mm ID tubing with an 0.127 mm wall and in pure aluminium is not commercially available it had to be fabricated. The fabrication route selected was to roll form and seam weld using electron beam welding. EBW was chosen because the MTC had considerable experience with this process on similar applications. Many welding trials were made using butt and lap configurations before settling on an 0.7 mm overlap.

To form the tubes, the pure aluminium foil was cut into 500 mm lengths by 252 mm wide. These sections were rolled to form tubes of 80 mm ID with an overlap of 0.7 mm at the seam. Accurate alignment of the edges was obtained by clamping both sides of the seam against an internal mandrel; the fixturing for this purpose is shown in figure 2. A centre groove of 1.5 mm width and 1.5 mm depth was machined along the entire length of the mandrel and a 1.5 mm diameter copper rod inserted

in the groove; this provided the back-up support for the seam weld. The preformed tube was then placed around the mandrel so that the overlapped seam was on top of the copper rod. The clamping plates were then bolted along both sides of the seam to give clamping over the entire 500 mm length.

Using the following electron beam parameters, number of thin-walled tubes were fabricated with excellent weld quality:

Power and work speed settings:

Power 20 kV @ 7 mA

Work speed 70 i.p.m.

Total energy input was calculated at:

$$\frac{\text{kV} \times \text{mA} \times 60}{\text{i.p.m.} \times 1000} = 0.12 \text{ kJ/inch}$$

3.2 Joining of Thin and Thick Tubes

Considerable effort was expended in developing the technology for welding the thin (0.127 mm) and thick (2.0 mm) sections of the assembly. Electron beam welding trials with various square butt and lap configurations together with manipulation of beam parameters proved unsuccessful. In all cases the thin section distorted away from the thick section when heated, even when the ends of the thin section were carefully clamped.

After all the conventional weld configurations failed, an unconventional technique was tried. The thin sheet was flared to form a 2 mm flange at an angle of 90 degrees to the tube, and the flanged portion sandwiched between two thicker (2 mm) sections. The 'sandwich section' was then electron beam welded from the top [Fig. 3].

Various beam power and speed settings revealed that a full penetration weld was not feasible since there was still a danger of melting the thin section immediately outside the protection of the sandwich, however, welds produced with about half of the full penetration were of good metallurgical quality. A micrograph of a typical sandwich-type weld shows complete fusion of the thin section, directional solidification and little or no porosity in the melt zone [Fig. 4].

The following electron beam power settings were used:

Power 45 kV @ 18mA

Work speed 73.6 i.p.m.

Energy input was calculated as:

$$\frac{45 \times 18 \times 60}{73.6 \times 1000} = 0.66 \text{ kJ/inch}$$

For the welding of the thinner central tube to the thicker end tubes, a 500 mm long mandrel was designed and manufactured. The mandrel was designed such that it could be collapsed down to about 78 mm OD and expanded to about 81 mm OD. End attachments (non-collapsible 80 mm OD) were also made for the mandrel so that the length was extendible to full 800 mm. The main function of the expansible mandrel was to hold the fragile 500 mm long thin tube tightly and rigidly for welding without damage.

End rings [Fig. 3 and 5] were made for each tube. The inside diameter of the rings was 80.254 mm, making a gap between the thin tube and the ring wide enough for the insertion of one ply of carbon fibre composite. Twelve holes of approximately 6.0 mm diameter were drilled in the wall of the end fitting to provide additional area for adhesive bonding.

The two end tubes with 80 mm ID, 2 mm wall thickness and 150 mm length [Fig. 1] were machined from an Al-3Mg tube provided by the DESY laboratory.

A number of these electron beam welded tube assemblies were made and supplied to the University of Toronto for the application of carbon fibre epoxy reinforcement. Figure 6 shows a complete welded assembly as supplied to the University.

3.3 Carbon Fibre Epoxy Lay-up and Curing on the Thin Tube

Carbon fibre epoxy reinforcement to the central thin tube was applied and cured at the university laboratories. The welded assembly was placed on a full length mandrel, and then about 7 layers of carbon-fibre epoxy prepreg tape (AS/3501-6 manufactured by Hercules Incorp.) was applied in cross-ply orientation (oriented at $\pm 30^\circ$ to the tube axis). Curing was done at a pressure of 85 p.s.i. and 176°C. The mechanical work was done at York University and the curing was done at the University of Toronto. Figure 4 shows a complete tube with carbon fibre epoxy reinforcement.

4.0 Testing

Mechanical and vacuum testing of the tube was done at the DESY laboratories. Although, no formal test reports have been issued on this work, informal feed back has revealed that a complete assembly was successfully tested and will be installed in the detector.

5.0 Discussion

No definite conclusion can be drawn regarding the success of the beam tube development until operating results are obtained.

Although the composite tubes offer a relatively inexpensive alternative to beryllium, the use of the electron beam welding process does make the manufacture rather specialized. The manufacturing process could, however, become more widely accepted and simplified by the use of the YAG laser process, which was not available at the time of this study in the Manufacturing Technology Center. While an actual beam tube has not been made with the laser, sufficient related manufacturing work has been done at NRCC with laser welding to make the prediction with considerable confidence.

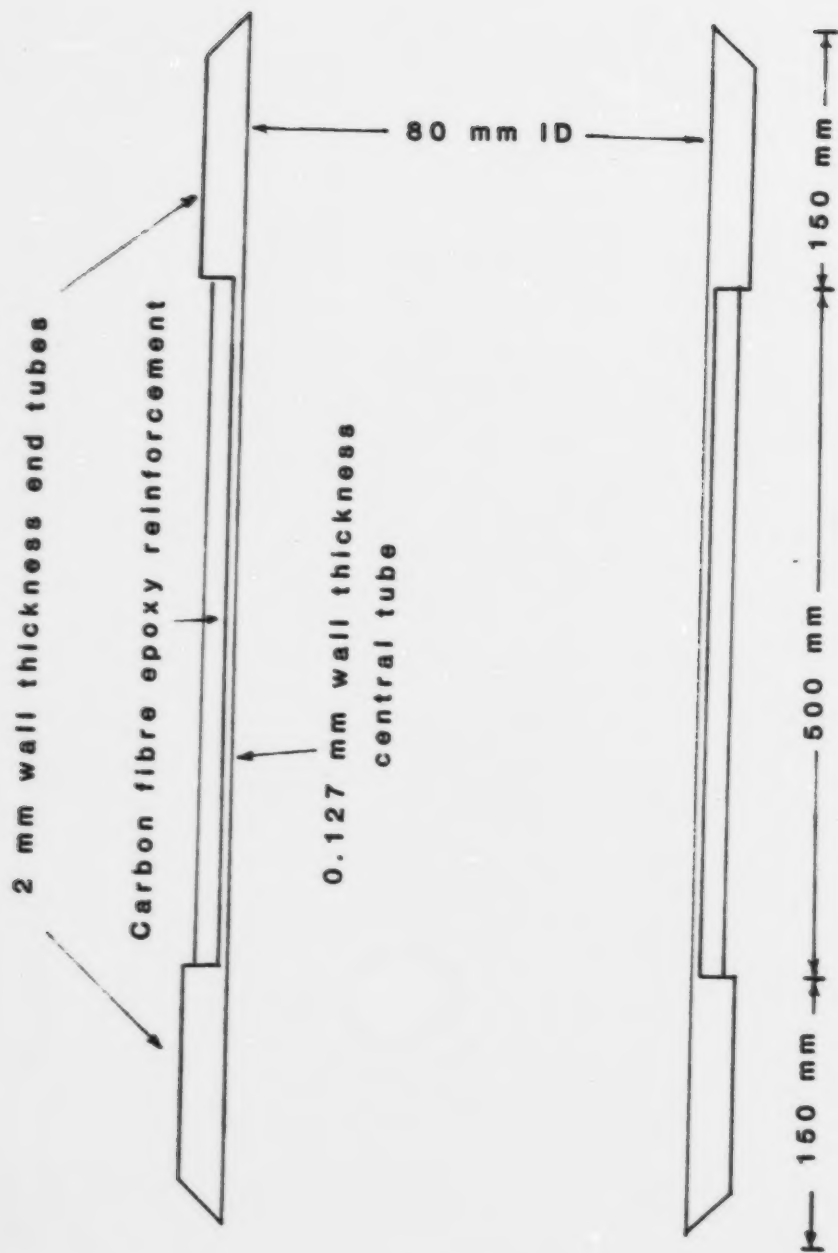


Figure-1 : Schematic drawing of the tube assembly.

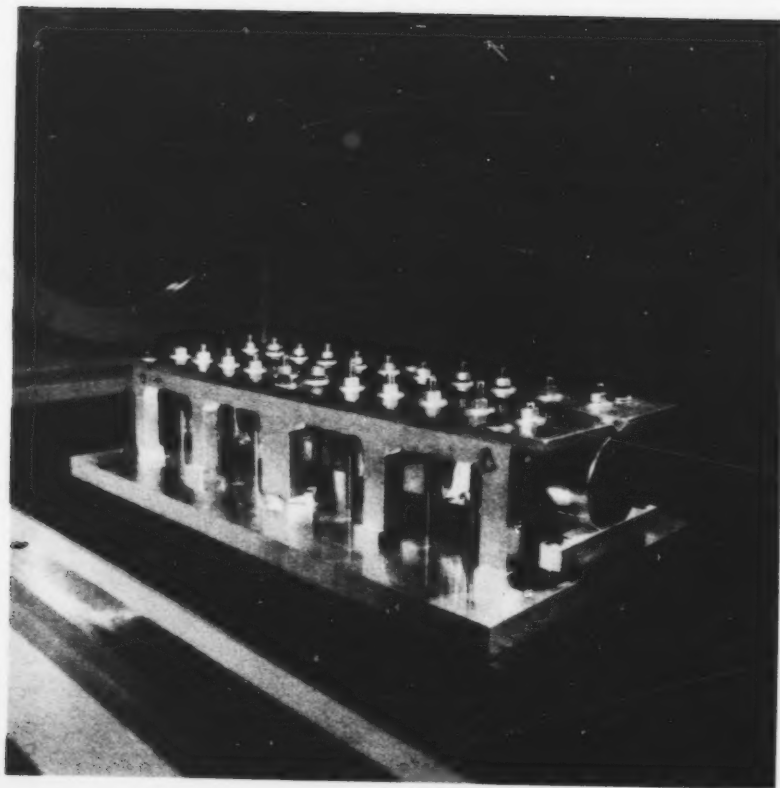


Figure-2 : Clamping arrangement for the seam welding of the thin tube.

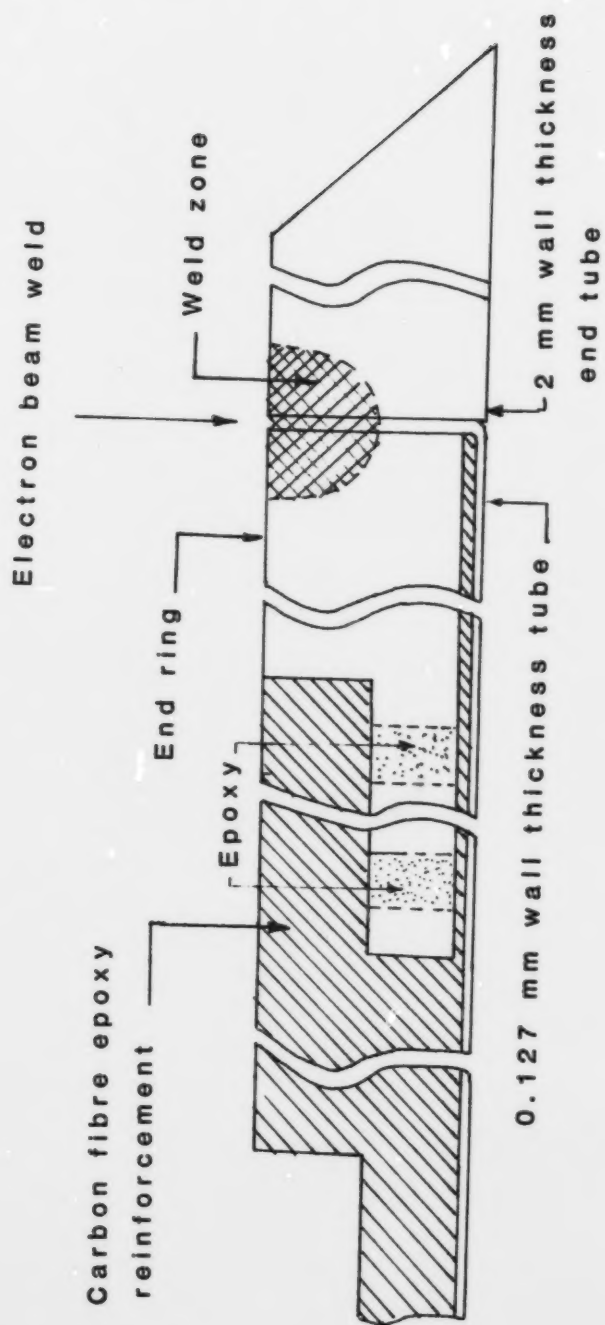


Figure-3 : Configuration for the electron beam welding of the thick and thin tubes and carbon fibre epoxy reinforcement.

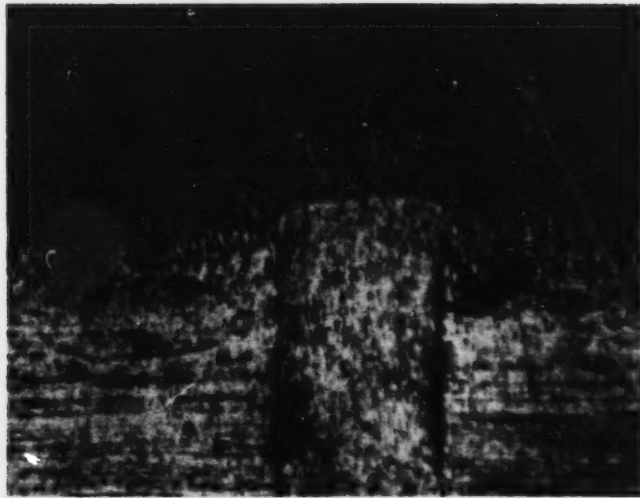


Figure-4 : Weld zone, magnified 240 times.

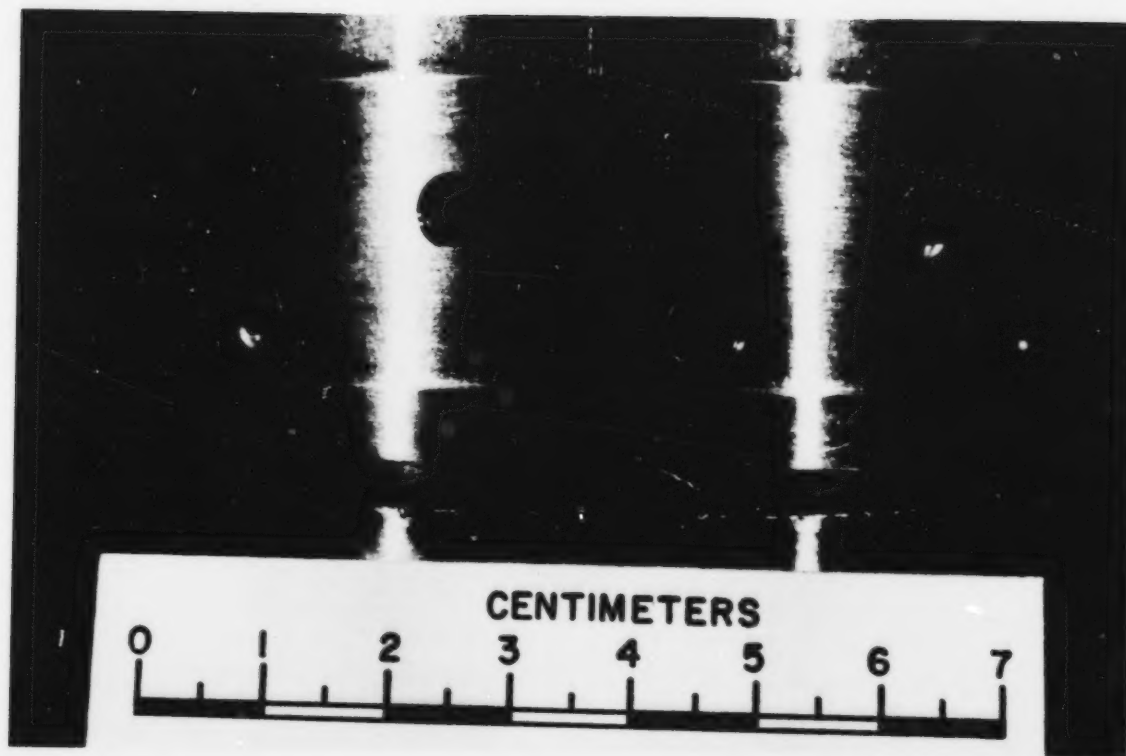


Figure-5 : Photograph showing one welded end of the tube.

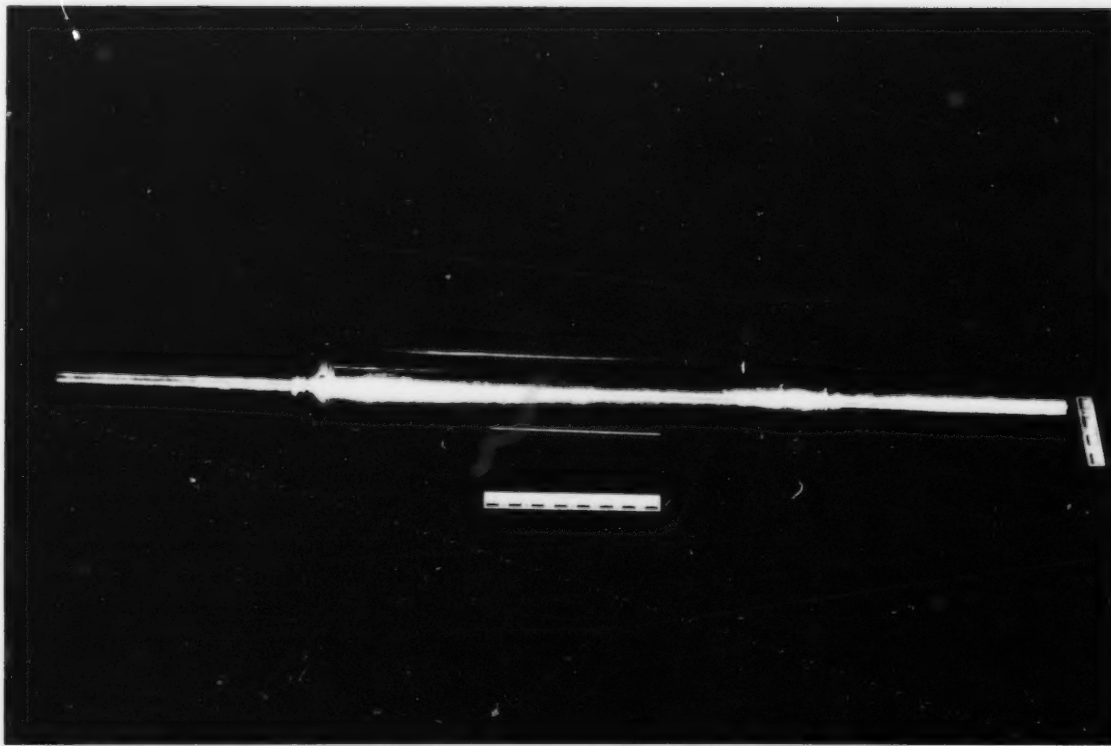


Figure 6 : Photograph of a complete (trial) welded assembly.

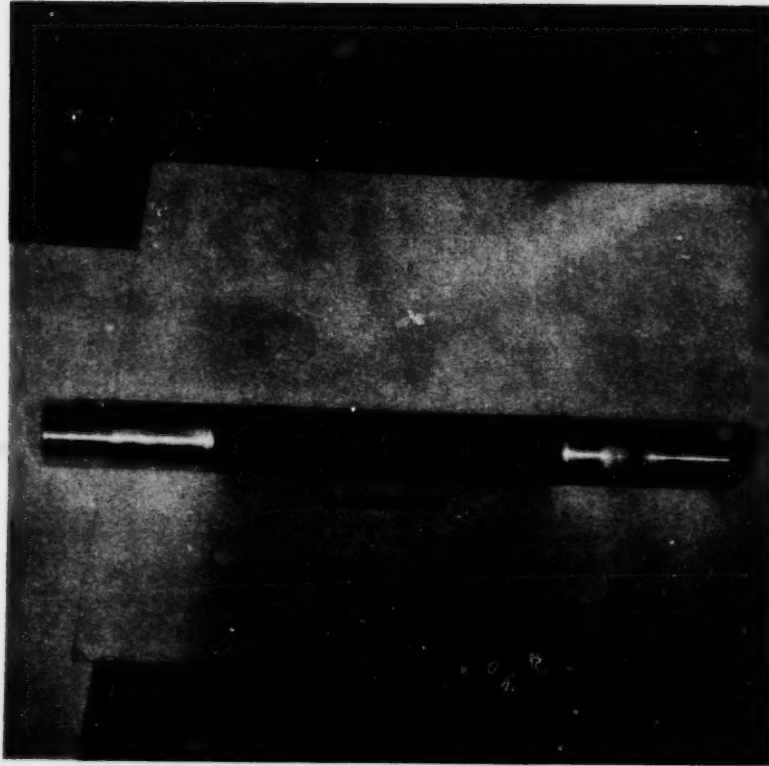


Figure-7 : Photograph of a complete tube with carbon fibre epoxy reinforcement.

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ADDRESS/ADRESSE Gavin McGregor, General Manager, Manufacturing Technology Centre, Division of Mechanical Engineering, National Research Council of Canada, Ottawa, Ontario, K1A 0R6. Telephone (613) 993-2436 16					